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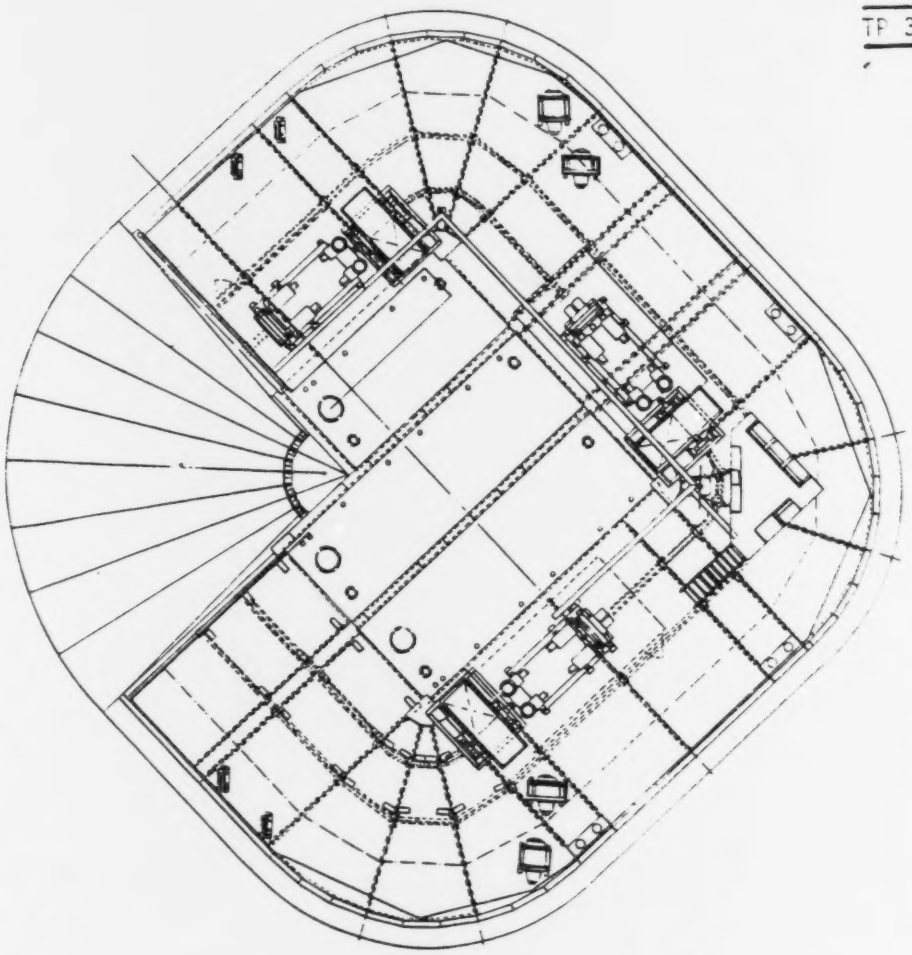

Design review and conceptual design

of interim notch seal

Air Cushion Ice-Breaking Bow HSL-533

Prepared for

Transport Canada

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Library and Information Centre /
Centre de Documentation GSLA
Ottawa Canada K1A 0N5

FINAL REPORT

DESIGN REVIEW AND CONCEPTUAL DESIGN OF INTERIM NOTCH SEAL AIR CUSHION ICE-BREAKING BOW HSL-533

Contract Nos. 4475/4478

Ref. D1460-163-14-2

Report No. 7575-950002

Prepared for

Transportation Development Centre (TDC)
Transport Canada, Montreal

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September 1981

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REPORT DOCUMENTATION FORM

1. Transport Canada Report No.	2. TDC Project No.	3. Recipient's Catalogue No.
TP 3332E	4475 and 4478	

4. Title and Subtitle	5. Report Date
DESIGN REVIEW AND CONCEPTUAL DESIGN OF INTERIM NOTCH SEAL FOR HSL-533 AIR CUSHION ICEBREAKING BOW	September 1981
	6. Performing Organization Report No.
7. Author(s)	8. Transport Canada File No.
G.R. Tothill/A.Y. Simpson	D1460-163-14-2
9. Performing Organization Name and Address	10. DSS File No.
Bell Aerospace Canada Textron Division P.O. Box 160 Grand Bend, Ontario N0M 1T0	-
	11. DSS or Transport Canada Contract No.
	4475 and 4478
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Transportation Development Centre (TDC) Transport Canada 1000 Sherbrooke Street West Montreal, Quebec H3A 2R3	Final report
	14. Sponsoring Agency Code
15. Supplementary Notes	16. TDC Project Officer
	N.E. Rudback

17. Abstract

The air cushion auxiliary icebreaking bow, HSL-533, built in Calgary by Hoverlift Systems Ltd. for the Canadian Coast Guard, had been in storage for more than a year and required inspection before it could be put back into use. In addition, the pneumatic structure for mating to the pusher ship had not been operating properly. The contractor, therefore, had to also develop a temporary method allowing the introduction of the ship stem into the air cushion space.

Following the inspection, 1/10 scale models of the junction area of the auxiliary bow and of that of the CCGS "Griffon" were built in order to study possible corrections to the junction mechanism. After selection of a proper solution, a stress and weight analysis was carried out to confirm the validity of the solution chosen.

The solution consists of eight articulated frames taking up the forces applied to the flexible segments by the cushion pressure. The segments themselves, as well as the other components of the auxiliary bow, particularly engines and fans, were judged correctly sized. However, the buoyancy reserve, when the bow is floating without the air cushion, is limited at the maximum design weight.

18. Key Words	19. Distribution Statement
Notch seal, air cushion, icebreaking, buoyancy.	Limited number of copies available from TDC

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price
Nil	Nil		Nil

TDC CDT 79-005

FORMULE DE DOCUMENTATION POUR RAPPORT

1. N° du rapport Transports Canada	2. N° de l'étude — CDT	3. N° de catalogue du destinataire
TP3332E	4475 et 4478	

4. Titre et sous-titre	5. Date du rapport
DESIGN REVIEW AND CONCEPTUAL DESIGN OF INTERIM NOTCH SEAL FOR HSL-533 AIR CUSHION ICEBREAKING BOW	September 1981
	6. N° du rapport de l'organisme exécutant

7. Auteur(s)	8. N° de dossier Transports Canada
G.R. Tothill/A.Y. Simpson	D1460-163-14-2

9. Nom et adresse de l'organisme exécutant	10. N° de dossier — ASC
Bell Aerospace Canada Textron Division Case postale 160 Grand Bend, Ontario NOM 1TO	11. N° de contrat — ASC ou Transports Canada 4475 et 4478

12. Nom et adresse de l'organisme parrain	13. Genre de rapport et période visée
Centre de développement des transports (CDT) Transports Canada 1000, rue Sherbrooke ouest Montréal, Québec H3A 2R3	Rapport final
	14. Code de l'organisme parrain

15. Remarques additionnelles	16. Agent de projet — CDT
	N.E. Rudback

17. Résumé

La proue brise-glace auxiliaire sur coussin d'air, HSL-533, construite à Calgary par Hoverlift Systems Ltd. pour la Garde côtière canadienne, était immobilisée depuis plus d'un an et une inspection devenait nécessaire avant sa mise en opération. De plus la structure pneumatique de jonction n'étant pas au point le contracteur devait aussi étudier une méthode intérimaire permettant l'intromission de l'étrave du navire propulseur dans l'espace défini par le coussin d'air.

Suite à l'inspection, des modèles à l'échelle 1/10 furent construits de la structure conjonctive et de l'étrave du CCGS "Griffon" afin d'étudier les corrections possibles au système. Après sélection d'une solution adéquate une analyse de résistance et de poids devait confirmer sa faisabilité.

La solution proposée introduit huit formes métalliques articulées qui reprennent les charges imposées aux segments souples par la pression du coussin. Les segments eux-mêmes ainsi que les autres composantes de la proue auxiliaire, en particulier les moteurs et les ventilateurs ont été jugés correctement dimensionnés. Cependant la réserve de flottaison, lorsque la proue flotte sans le coussin d'air, est faible au poids maximum prévu.

18. Mots-clés	19. Diffusion
Jonction, coussin d'air, brise-glace, flottaison	Nombre limité de copies disponible au CDT

20. Classification de sécurité (de ce rapport)	21. Classification de sécurité (de cette page)	22. Nombre de pages	23. Prix
Nil	Nil		Nil

CDT TDC 79-005

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the advise and assistance provided by the personnel of the Canadian Coast Guard and Eyretechnics Limited, in particular J. Melhuish, M. Ball, R. Wade, J. Russell, and C. Carter.

SUMMARY

The ACIB was first inspected at Calgary to determine the current state of repair of the major components of the lift system and to obtain first-hand impressions of the work required to develop an interim notch seal. A 1/10-scale model of the notch seal and the CCG *Griffon* were then constructed so that alternative concepts for the notch seal could be tested and evaluated. At the same time, an assessment of the air supply system and the hullborne stability was conducted. Once the preferred design had been selected, a preliminary structural analysis was performed so that the size and weight of the component parts could be calculated to determine the practicality of the proposed modifications to the ACIB.

The notch seal modification is essentially a support structure cantilevered over the existing notch seal fingers and attached to them by flexible ties. The existing internal high-pressure tube system is to be removed in total, and the very large upward loads generated by the notch finger segments will be carried by eight hinged trusses back to the main structural components of the ACIB hull.

The remaining parts of the seal system appear adequate for the trials, and the lift engines and fans are well matched to provide sufficient airflow to the seal system for full inflation and specified hover height. The buoyancy, however, gives some concern, particularly at maximum weight conditions where the aft end of the main deck is almost awash.

No major roadblocks for the planned 1982 winter trials have been uncovered. However, it is recommended that precautions are taken during the trials with regard to the meager buoyancy margins, particularly at maximum weight.

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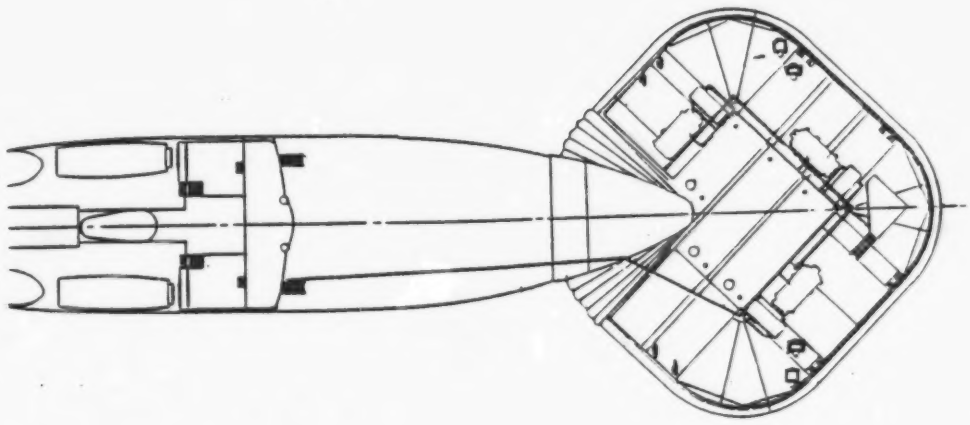
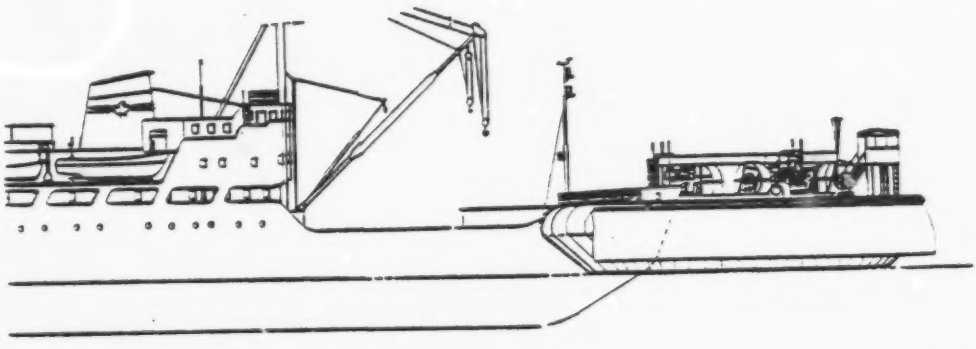




ICE BREAKER BOW ATTACHMENT

1. INTRODUCTION

This report covers the preliminary evaluation made by Bell Aerospace Canada Textron of the Air Cushion Ice-Breaking (ACIB) Bow Platform HSL-533. The objective of this evaluation is to assess the extent of modifications, or redesign, necessary to ensure that the notch seal functions sufficiently well to permit trials to be conducted during January and February 1982.

Earlier tests of models and full-scale prototypes had indicated that a significant portion of drag due to ice breaking could be eliminated if the ACIB platform was located adjacent to, or partly enveloping, the bow of the ship. In selecting the latter configuration, Hoverlift Systems, Ltd., Calgary, introduced an extended segment for the notch seal area that was also to have allowed the ACIB to operate on cushion with or without being connected to the ship. This section of the seal malfunctioned during the initial tests over land and was the major contributing factor in the subsequent closing of the project.

The Bell evaluation of the problem area, while maintaining the basic segment configuration, has led to a different approach in which it is intended to support the notch segments during the difficult inflation period to provide the necessary large stable upward resistance during operation and to facilitate controlling the segments during bow insertion. Additional investigative work uncovered other areas of the design with potential problems. For instance, the proposed procedure for connecting the two craft with the ACIB on cushion is unworkable without extensive modifications; the very-limited free board at full weight (102 mm at the aft end) could easily lead to partial deck flooding during off-cushion operation and severe airflow path restrictions to the notch seal area are present, particularly during partial cushion operation. Further studies are required to fully cover the areas of concern listed above and to generate corrective procedures and/or modifications. However, sufficient work has been done during this initial phase to warrant a Bell recommendation to continue the project on the basis of modifications to the existing equipment within the set time frame, rather than to attempt a full-scale redesign.

Without the limitations of the extremely tight schedule forced by setting the trial period for the coming winter season, the Bell approach may well have been radically different. Two options were available: either the permanent notch seal approach similar to our earlier work in 1978 on the original ice breaker proposal, or a self-stabilizing segment seal design somewhat similar to the current configuration. The final decision on the better approach hinges on the outcome of the full-scale trials this winter.

2. DISCUSSION

2.1 ACIB Inspection

The ACIB HSL-533 was inspected at Calgary in mid-August 1981, during this period the lift engines and fans were being checked and serviced. Due to misalignment of the temporary craft supports, it was considered unsafe to generate any airflow for fear of possible slippage. Consequently, the inspection was strictly of the craft in a static off-cushion mode.

2.1.1 Standard Fingers (Segments)

The standard fingers, which are fitted at all stations other than the notch, appeared in good condition considering their exposure to ultraviolet radiation and ozone for at least the past 1-1/2 years. Typical ozone cracks were apparent in areas of stress concentration, particularly at the knee joints. However, the depth and width of the cracks appeared insufficient to allow significant sunlight degradation of the basic nylon cloth.

The bonded joints appeared unimpaired upon visual inspection, with no apparent peeling. Only destructive sample testing would have provided a quantitative answer as to their true condition, and since this would have meant fabricating replacement parts, this course was not available. The best method was to proceed with the test programme and to be prepared to repair any small failures as they occurred. Catastrophic failure is highly unlikely.

During the cushion side inspection it was noted that the port stern fingers were not closed off, whereas the starboard stern fingers were fitted with closing panels and trailing flaps. It is suggested that this asymmetry be left unaltered and considered as part of the test program, particularly in view of the schedule.

2.1.2 Notch Fingers (Notch Segments)

The notch fingers have not withstood the ravages of time and sunlight very well. Fairly severe ozone cracking was apparent close to the hull attachments on the upper surfaces adjacent to the inboard fittings for the high pressure hoses. A number of lifting patches were ripped or torn off and tears were visible in the regions of sharp projections from the hull and internal segment supports. Since the relatively large inflation loads generated by the notch fingers are carried over a short attachment length, a thorough check and stress analysis should be conducted prior to the trials programme. Local reinforcing may be necessary.

The visual impression and sheer weight of each finger (approximately 200 kg, 450 lb), not including the ten 19.7-mm-diameter (5-inch-diameter) water-filled pipes and fittings, provided the first clues to the initial

problem; that is, the difficulty in priming the system from rest. Reports and photographs of the early trials and our own model tests (see 3.0) bore this out.

Theoretically, the segment fingers (if they could be inflated) are totally unstable, being quite unable to provide the necessary downward moments to resist the pressure loads generated by the cushion (if one could be contained). In addition, large inflated structures at relatively low inflation pressures (the fingers) and high-pressure flexible tubes (the internal support tubes) are notorious for their propensity to twist upon inflation, due to weaving and fabrication misalignment. The geometry of the notch fingers with the relatively large outboard ends and narrow inboard attachments is of little use in combating self-generated torsion loads.

Extensive modifications will be necessary to cure the above problems, a task enlarged by the sheer size of the seal components involved (to be appreciated only by direct inspection) and by a schedule that leaves no alternative other than modification. There was insufficient time to design and fabricate a new set of notch fingers. (See 2.2.)

2.1.3 Air Leakage

The lift system assessment (see 2.5) indicates a total flow sufficient to accommodate approximately 1.3 m^2 (14 ft^2) of cushion leakage area. Generally, seals (segments) of the HSL-533 type and size may be expected to suffer from fairly large leakage areas at the outer attachment junction between adjacent fingers. With a total of 65 fingers, plus the fact that the fingers are uncropped and capped in 14 cases (more leakage due to buckling), the daylight gap, if any, could be minimal. It follows that additional quiescent leakage in the form of avoidable leaks from the hard structure components should be avoided.

During the inspection, it was noticed that a number of the buoyancy tank joint straps on the deck were poorly fitted, and the rubber gaskets were missing. In addition, a number of avoidable leaks were made obvious from inside the cushion by daylight streaming through. Since the air supply is not overly abundant, every effort should be made to reduce the leakage areas during reassembly.

2.1.4 Lift Engine Controls, Etc

Inspection of the electrical wiring and control system disclosed numerous disconnected wires throughout the ACIB. Also, there were numerous blown fuses sitting in the bottom of the control fuse box in the wheelhouse.

Attempts to start the diesel engines failed, due to problems with the electrical system.

In general, the electrical and control system was in doubtful condition, and appearances would indicate that extensive problems have been experienced in attempting to make the system work.

2.2 Notch Finger Modification

Due to the time element, option (B), "the design and installation of a new notch seal" was unfeasible. Even if a new notch seal system could be produced rapidly with full design drawings and flat patterns, it would not have been feasible to arrange for fabrication and shipping in the time available. The total material yardage to be manhandled and the length of bonded joints would have amounted to a time-consuming task, causing scheduling difficulties at the manufacturer.

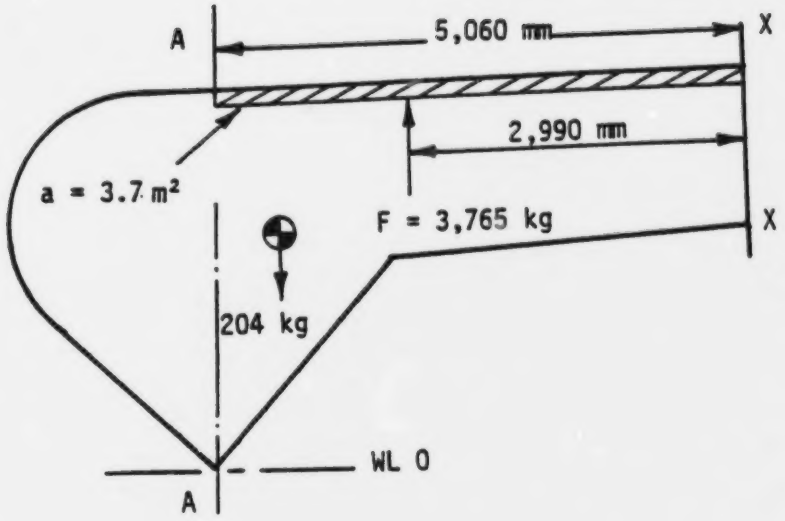
This left option A, to "modify the existing notch seal...", as the only possible alternative. The present seals had to be made to function sufficiently well to meet the ground rules for the interim notch seal. These ground rules stated that a working seal must be provided that will permit trials to be conducted between January 1, 1982, and February 28, 1982. Thus, in view of the schedule, the modification was required to be the simplest possible, in order to take the least time to install and to provide minimum risk.

Having arrived at this point, the reason for the unsatisfactory operation of the original fingers had to be established before a suitable modification could be developed. Figure 1 shows the approximate loading conditions attained by the individual notch seals, as originally designed, without the high pressure tubes and bracing apparatus. It will be noted that the vertical loads outboard (to the left) of AA and A'A' are balanced, which leaves the weight of the finger and upward pressure loads to be resolved. It should also be noted that to obtain the full-cushion mode, the seals have to pass through the partial cushion condition in which the vertical loads are almost twice as severe.

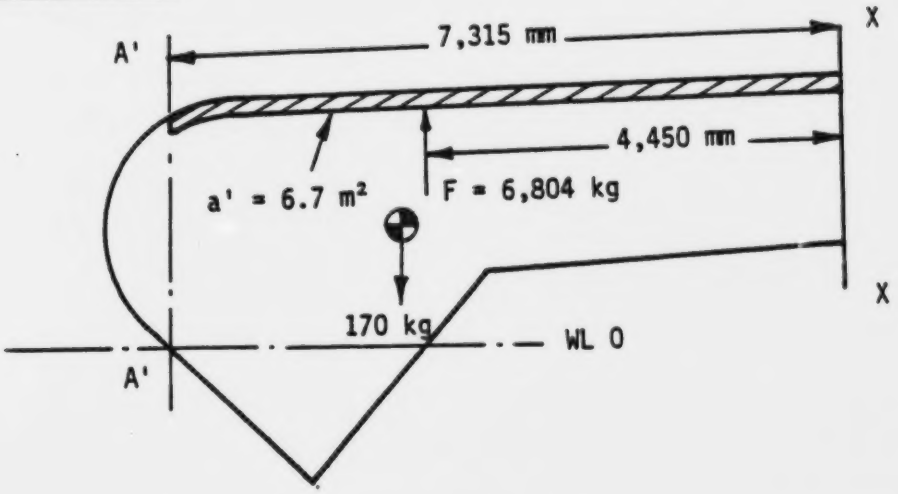
Extremely large, unbalanced vertical loads are involved that have to be carried by the modified notch finger. Three possible alternative systems for generating the required stabilizing forces were considered during the assessment. They are as follows:

a. Water Ballast System - An array of off-the-shelf water bags would be attached to the inside walls of each finger with sufficient capacity to cover the worst condition. In addition, a pumping system capable of removing 22,730 litres (5,000 Imperial gallons) of antifreeze liquid from the bags to a holding tank during full-cushion generation is required in

On-Cushion Case



Partial-Cushion Case



Note: Net Change Between Two Cases = 3,039 kg

Figure 1 Notch Finger Loads Due to Cushion Pressure

order to maintain balance. The system is attractive because no rigid components are located in the vicinity of the notch fingers and the water bags are relatively simple to install. However, the system suffers from a lack of rapid fine-tuning capability and a simple feedback system to ensure that balance margins are being maintained during operation.

b. Air Inflated Structure - By closing off the upper portion of each segment from the cushion by the addition of a horizontal member and a number of vertical diaphragms, the resistance to buckling could be increased significantly, depending on the local inflation pressure. A simple air pressure system could be run off the lift engines; however, the major problem with this alternative is safety. A pressure of 172 kPa (25 psi) would be necessary in order to achieve individual finger stability, and a structure this size inflated above 35.5 kPa (5 psi) would be courting disaster. Material selection and fabrication would also present serious difficulties.

c. Internal or External Trusses - By constructing a rigid frame so that it overhangs the fingers and is also attached to the fingers, all of the inflation loads could be accounted for, with the additional advantage of providing support during the inflation period before cushion sealing pressures have been obtained. Hinging the frames at the junction between fingers and hull would provide the required dual geometry for connected and unconnected operations. The frames, or trusses, could be installed inside the fingers for less overall weight and a more elegant approach. However, segment removal would be difficult, and engagement with the mother ship more complicated due to the lack of suitable external strong points.

It was clear at this stage that the third alternative provided the only practical approach to all the requirements for the modification. Therefore, more detailed studies were conducted on the truss system to ensure that strength, weight, and operating characteristics were compatible with the ACIB. These generally took the form of a 1/10-scale model test programme and a loads analysis conducted in parallel.

2.3 Rig Development

Past experience has shown that whenever the stability of a proposed skirt system is in question, the best approach is to make an accurate working model at the largest scale possible. A much clearer insight into the working characteristics of the system can be obtained by this means than by any other, short of a full-scale prototype.

In this case, a 1/10-scale model was selected as being the largest an existing Bell-owned test fan could operate with a maximum cushion pressure of 101.6 mmH_2O (4.0 inH_2O). Only one quarter of the ACIB was modeled; even

so, when combined with an in-scale ship bow module, the overall rig dimensions became quite large and fabrication becomes expensive. Figure 2 shows a sketch of the general arrangement of the rig viewed from the underside. Two standard fingers were included on either side of the eight notch fingers to provide a realistic interface for the test fingers. Air was supplied via a flexible duct from above the rig feeding through the carousel. This method approximated the full-scale flow paths to the notch fingers. It was interesting to note that unassisted inflation from rest could not be achieved until scaled feed holes had been drilled through the cylindrical vertical face of the carousel.

Of the eight hull lines of available Canadian Coast Guard (CCG) icebreakers, the *Griffon* had the largest half angle at the bow, 43 degrees compared with 37.5 degrees, the next largest. Since it was considered that bow configurations with the larger included angles would present the greatest sealing problems, plus the fact that CCG *Griffon* was a possible initial choice for the upcoming trials, it was selected to be modeled. However, it now appears that the CCG *Alexander Henry*, with its 36-degree half angle, will be used.

The model skirt fabric was nylon material, coated on both sides with 170 gm/m^2 (5.5 oz/yd^2) nitrile rubber. This was the lightest fabric available at short notice, since it is used for the majority of Bell model skirts. At 1/10 scale it provided near-correct weights and stiffness characteristics, although its draping ability was not optimal. All the joints in the skirts were bonded and sewn to provide a robust model that could be manhandled during testing.

2.4 Truss Design

It was decided early in the test programme that in order to obtain positive initial inflation, adjacent fingers must be joined together. By attaching them along their length at the upper tangency point, a valley is made between the fingers that provides a natural location for the bottom edges of the trusses. If the first notch finger is attached along the vertical face of the adjacent hull in a similar manner, eight trusses are required. The two centre trusses carry only one-half the full finger load, but require extra strength to interface with the ship bow. A typical truss is shown in figure 3. The concept also calls for flexible ties between the fingers and the frames to provide finger support prior to inflation. So that the relative motion between adjacent fingers and truss is kept to a minimum when the trusses are swung open to allow insertion of the ship bow, the axis of the truss hinges should be as close as possible to the vertical finger attachments to the carousel. This calls for radial fanning out of the truss hinges around the edge of the carousel.

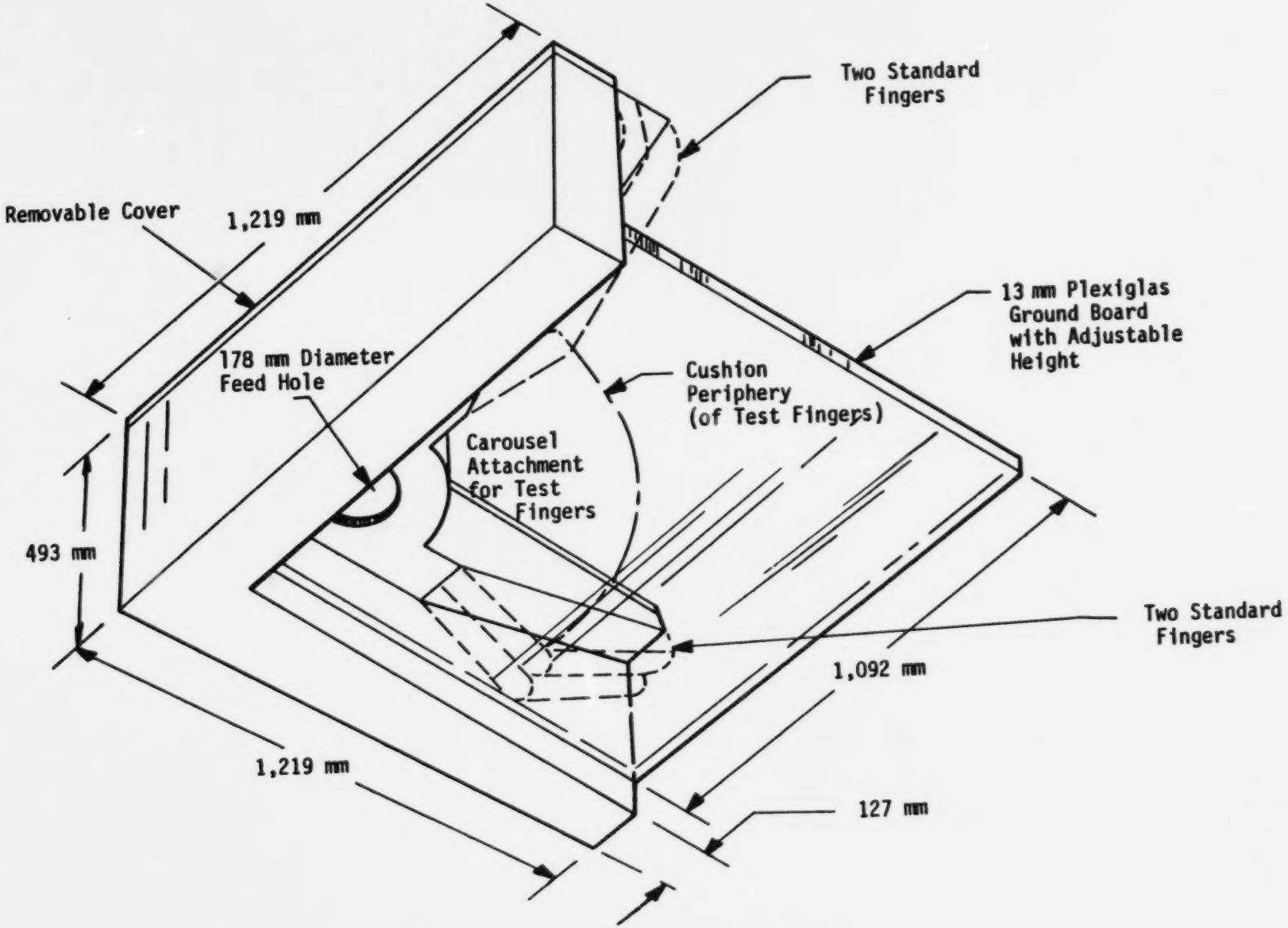


Figure 2 1/10-Scale Rig Viewed from Underside

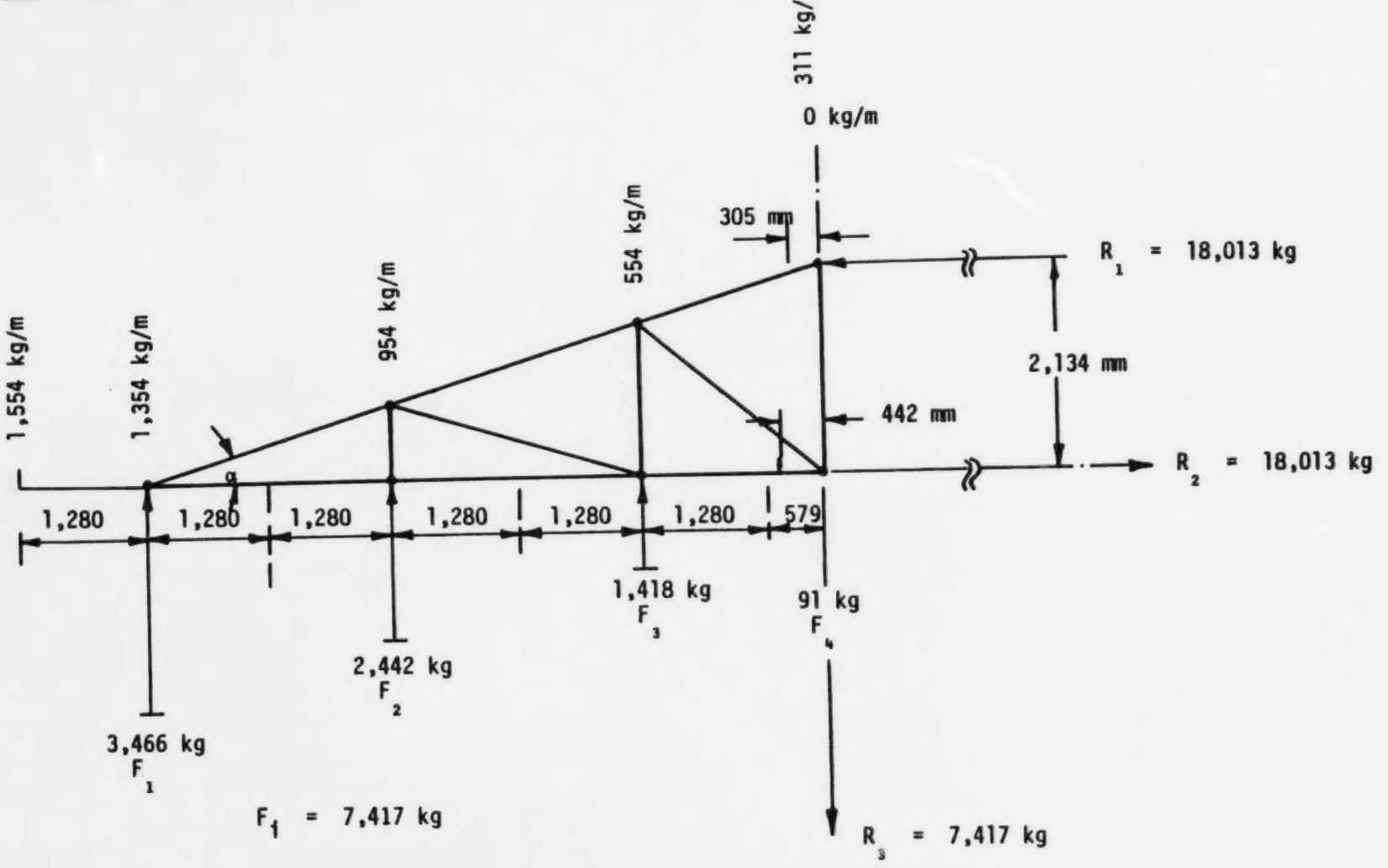


Figure 3 Typical Hinge Truss Support for Notch Fingers

The actual method of attaching the trusses to the hull has not yet been resolved. Two concepts have been considered (figure 4). The second concept is less bulky than the first but may interfere with the finger attachments to the hull. It is expected that the wheelhouse may be moved from its existing location where it can come into contact with the ship's bow in some conditions. If this is the case, the truss height can be increased from the 2.13 metres (7 feet) considered initially, and the remaining support frame can be reduced in size.

The preliminary study indicated that steel truss cross sections of 4 in. × 4 in. × 3/8 in. or 5 in. × 5 in. × 1/4 in. would carry the loads satisfactorily, and would weigh about 9,070 kg (20,000 lb), including the support frame. Weight savings of between 907 kg (2,000 lb) and 3,175 kg (7,000 lb) may be made by converting to an all-aluminium truss and support frame structure, depending on the selected allowable stresses, wall thickness, and availability. The aluminium beam section would need to be at least 5 in. × 5 in. × 3/8 in.

The final beam material selection should not be made until more detailed analyses of the requirements have been carried out. When practical aspects are considered, such as interfaces with the existing steel structure, fatigue characteristics of aluminium in possible salt spray environment, availability, and fabrication experience, it is believed that potential weight savings will not be a major factor in material selection. Presently, Bell would recommend steel, even though some small weight penalty may result. In fact, steel need not affect the heavy weight condition of the ACIB, since sufficient concrete ballast may be off loaded, and only the minimum weight attainable would be curtailed.

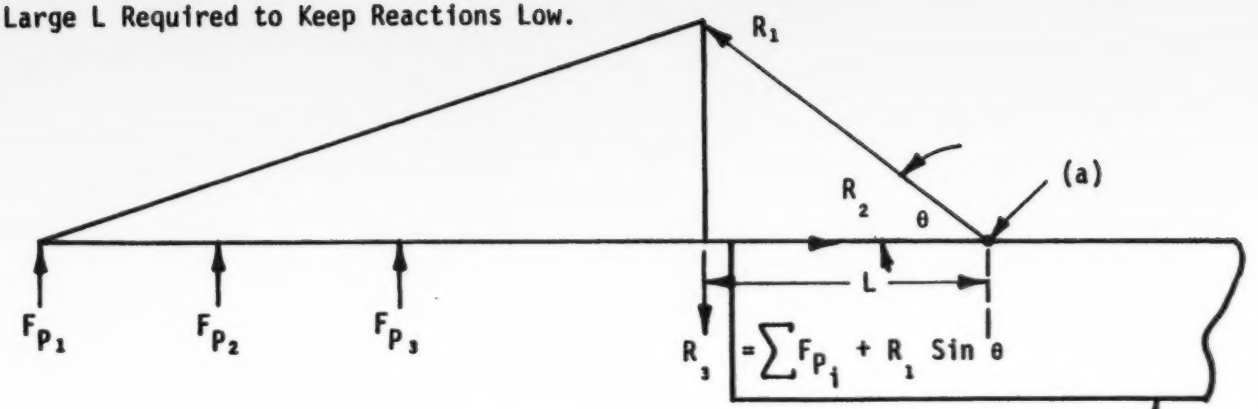
2.5 Lift System Evaluation

The HSL-533 lift system was evaluated with the inlet guide vanes (IGVs) fully open with the aid of a special in-house computer programme written for the task. It was determined that the total flow is sufficient to accommodate approximately 1.3 m^2 (14 ft^2) of total cushion leakage area. The fans were well matched to the engines, and most of the Hoverlift predictions appeared to be correct. (See 3.2 for results.) In addition, it appeared that the total lift horsepower was adequate when compared with other similar heavy lift platforms (figure 5).

Evaluation of the lift flow calculations and overall model test results lead to the conclusion that the ACIB will achieve the minimum specified hover height of 1.6 metres over land, provided that no excessive leakage paths exist through the hull and outer finger attachments.

The calculated total cushion leakage area of 14 ft^2 was probably insufficient to allow the craft to lift beyond the so called squared tip

Concept 1: Large L Required to Keep Reactions Low.



Concept 2: No Large Down Load on Top of Deck at Point (a).
Minimizes Vertical Reaction;
Direct Shear at R_4, R_5.

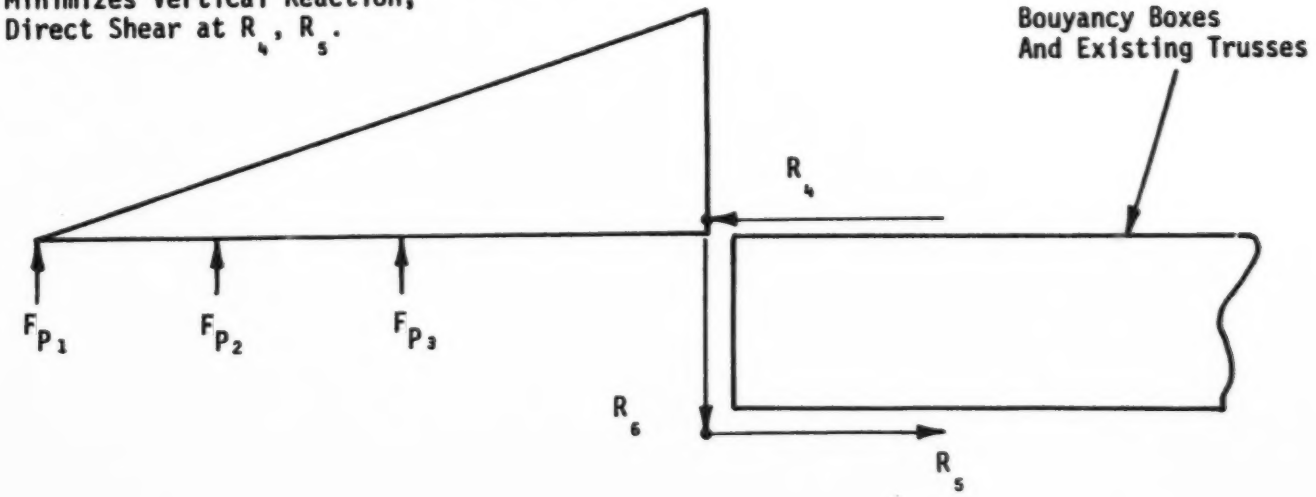


Figure 4 Alternative Methods for Truss Attachment to Hull

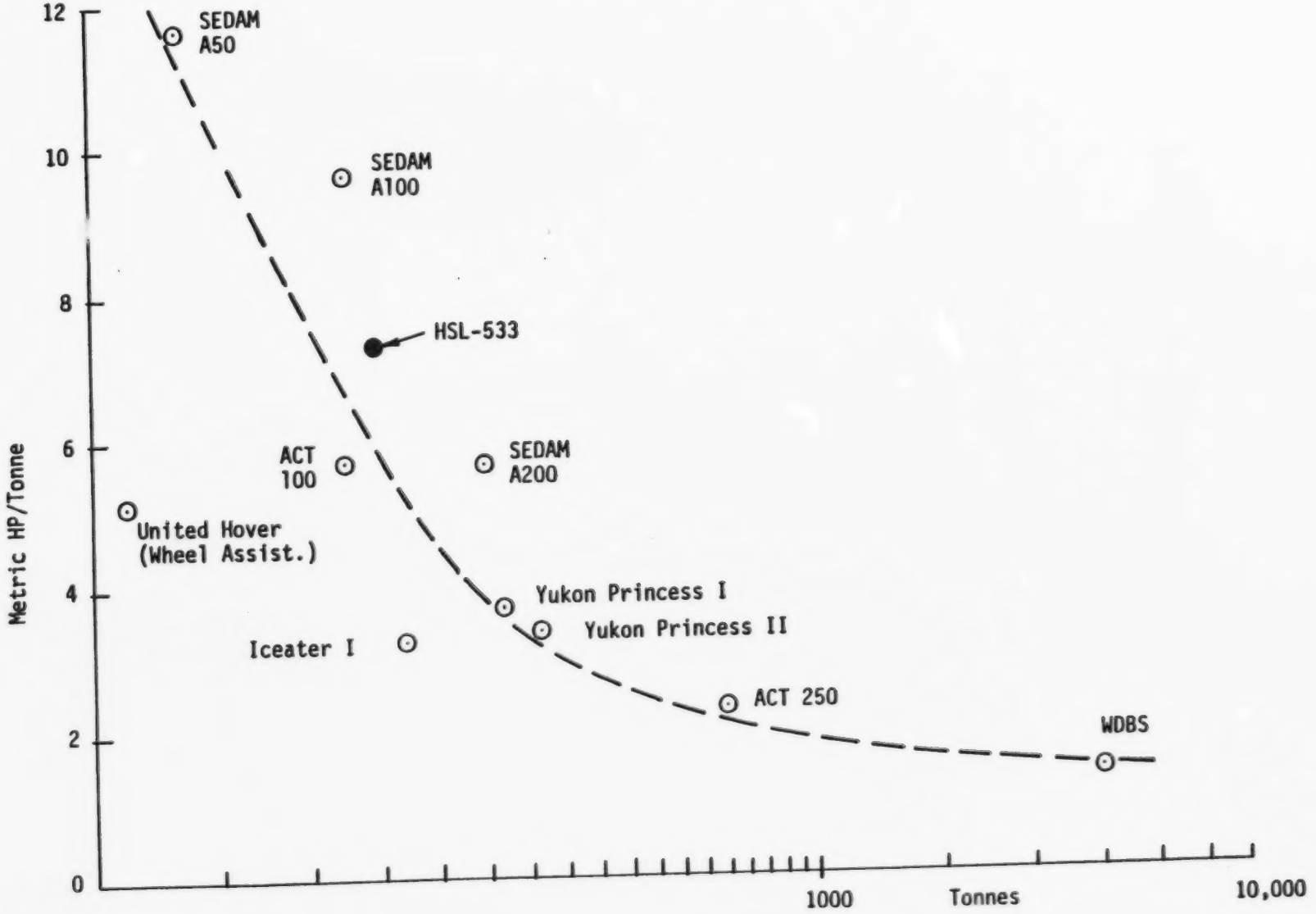


Figure 5 Survey of Heavy Lift Systems
AUW Tonnes versus Metric Horsepower/Tonne

plane that provides a theoretical cushion height of 1.88 metres, less the 50 mm protective bottom on the buoyancy tanks.

2.6 Hullborne Stability Assessment

A complete hullborne stability study of the HSL-533 was beyond the scope of the initial contract, requiring many time-consuming inputs to a special computer programme. However, the hullborne stability predictions made by Case Existological Laboratories, Ltd., (CELL) have been checked by hand calculations. The results appear to be correct with the exception of the tonnes per centimeter immersion curve. Figure 6 illustrates the difference between CELL results and Bell predictions. However, the CELL displacement versus immersion curve appears to be correct, particularly in the region of two metres draft. It follows, therefore, that at the maximum displacement of 271 tonnes the ACIB will meet minimum requirements (a positive metacentric height, and positive freeboard), but with a very small margin of only 50.8 mm (2 in.) free board in the worst case. No account of either topside icing or any wake that may be generated by either vessel appears to have been taken. In the minimum displacement condition of 171 tonnes, the minimum freeboard will be approximately 500 mm (20 in.).

The worst case mentioned above occurs when the double bottom of the centre tri-tank is flooded while the ACIB is in the fully-ballasted condition. It would be prudent, perhaps, if the CELL analysis were expanded during the next phase of the programme, particularly because the damage cases have not been specifically checked by Bell. It is understood that the damage analysis was conducted on the premise that it would be most unlikely for the ACIB to incur rupture of the main buoyancy tanks (above the double bottoms). However, it appears that contact with solid ice might occur along the bow surfaces of the main buoyancy tanks between the bow deck/finger support trusses and below the lower buoyancy blocks. It has also been pointed out that the lower truss attachment fittings in this area form an unfavorable configuration with respect to riding over obstacles of ice that could pass through the bow fingers.

Therefore, it appears desirable that during reassembly of the ACIB and assembly of the buoyancy block attachment fittings, suitable protector/deflection plates are fitted in the bow region, provided the added weight is kept to a minimum.

There is also some concern with the overall dynamic stability of the ACIB and ship combination. It is quite feasible for bow down pitching moments of sufficient severity to be generated during clear water operation at speed that could put the bow deck under water. If this situation is allowed to occur without the limitation of safety strops, a major accident could take place. At the very least, the forward lift engine and fan installation would be swamped.

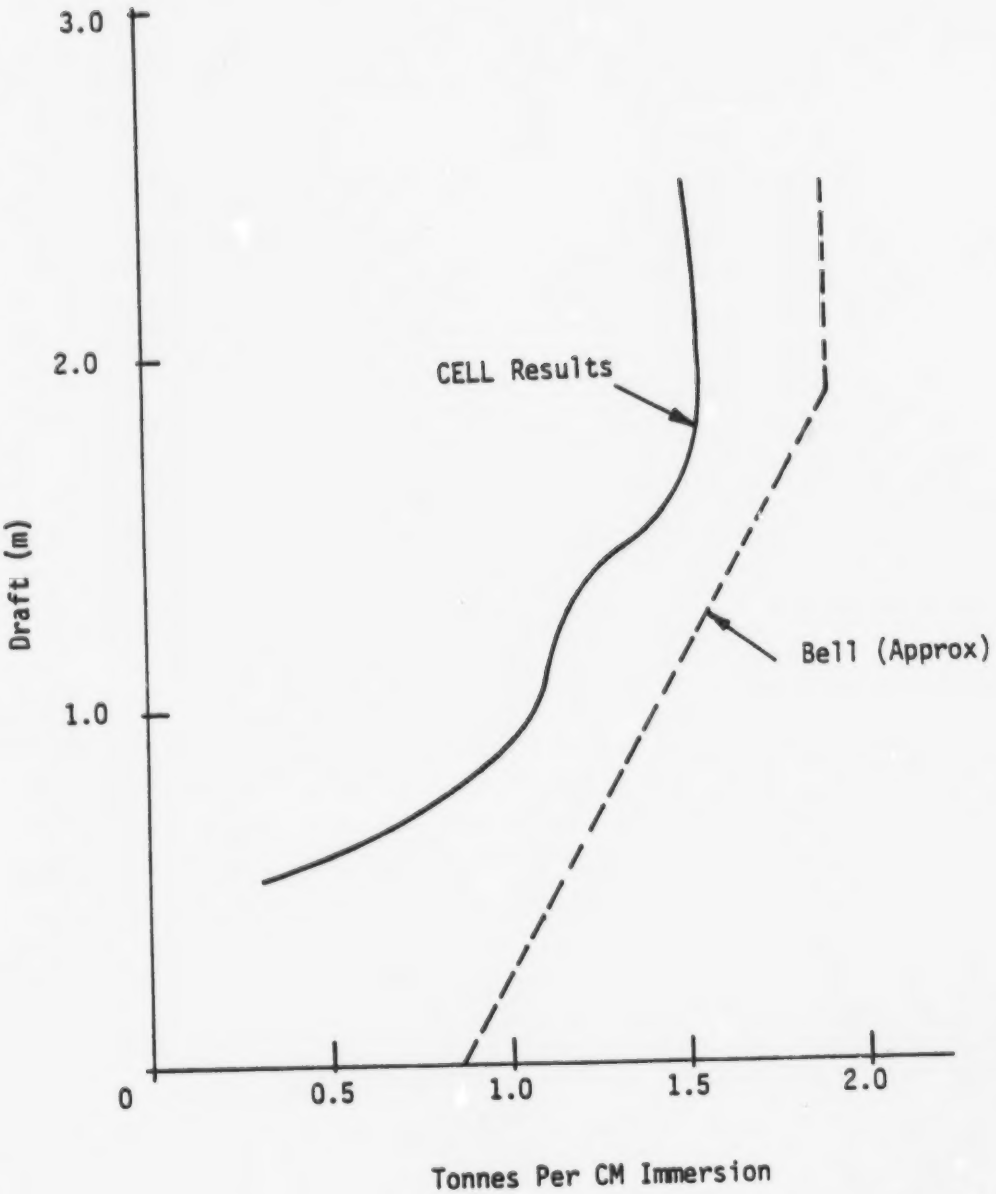


Figure 6 Comparison of CELL and Bell Results for Tonnes/CM Immersion versus Draft

The characteristics of air cushion systems are such that there is always a threshold speed at which the drag loads on the seal exceed the stabilizing forces of the cushion, and the craft will attempt to plough-in. The severity of this manoeuvre depends on many factors, including speed and bow hull shaping. The ACIB with its 1-to-1 length-to-beam ratio, possible net negative deadrise formed by the bow down attitude of the deck and forward buoyancy blocks (during plough-in), and massive momentum (of the combined unit) is highly vulnerable. However, with low speed (not more than 5 knots) and properly located and tensioned safety strops, a workable safety margin should be obtained for the upcoming trials. Notwithstanding the above, a programme of plough-in tests should be conducted at an early date to establish safe boundaries.

If, as a result of these tests, the plough-in boundary is found to be close to the normal operating conditions, the addition of a suitably angled bulwark on the two leading sides of the craft could provide considerable protection. The importance of adequate safety strops cannot be over-emphasized.

2.7 Notch Finger Priming

Inflation of the notch fingers from the hullborne mode, particularly at maximum displacement, may present a problem. In the present configuration the main air supply route to the notch fingers is somewhat tortuous. Lift air from the three fans flows outwards in passageways provided between the buoyancy blocks to the peripheral duct that runs above all the standard fingers. In addition, air flows downward into the standard fingers located directly under the radial airflow passageways. There is no direct connection between this air supply and the notch fingers due to the solid structure of the notch walls and the immersion of the buoyancy tanks. Consequently, the initial center of pressure of the lifting area will be well off the ACIB cg, causing a stern down trim, possibly putting the deck under water in the worst conditions. Until the notch fingers obtain sufficient (significant) airflow to form a seal, the out-of-trim tendancy will persist. Eventually, and it is by no means certain, air will flow under the buoyancy tanks and into the notch fingers at which time a balanced lift will occur.

To determine the exact sequence of events would be extremely time consuming, requiring step-by-step buoyancy and stability calculations. The most realistic approach would be to provide a direct air supply path to the notch fingers that is unaffected by hullborne conditions. Several possible methods of carrying out this provision are available, and cost complexity is likely to be minimal (less than the analytical procedure that could still result in the necessity for additional hardware). The alternatives will be investigated in the next phase of the programme to establish the most efficient method.

If the unmodified ACIB were launched onto water on cushion, it might not be easily retrieved if any of the three engine/fan systems fail, even for a moment. It should be pointed out that the lack of airflow to the notch fingers will only occur over deep water. There should be no such problems on land, or even in shallow water.

3. RESULTS

3.1 Rig Tests

3.1.1 Baseline Configuration

The initial set of rig tests were conducted during the second week in August 1981 with the notch fingers as they had been originally designed, but without any internal stiffening devices. It was found impossible to inflate the fingers, even when supported by several people.

Providing in-scale feed holes directly between the carousel duct and the fingers allowed all the fingers to inflate, but with a strong tendency to buckle upwards and release the cushion.

The fingers were attached to each other along their top edges and, subsequently, entire segments were attached along their mutual tangency lines. Fingers 4 and 5, finger 1 and the rig, and finger 8 and the rig were not attached. This modification caused either the left or right hand bank of four fingers to buckle upwards and release cushion pressure.

3.1.2 First Truss Tests

Pivoted trusses were installed at six locations and were attached individually to each finger junction at four places. This resulted in the two centre fingers rolling upward and lowering the cushion pressure. The two outer fingers also rolled upward but to a lesser degree (due to the solid hull backing against their outer sides). The configuration was quasi-stable. It was noted that there was a problem at the finger attachments to the trusses. The former needed to be kept short in order to locate the trusses centrally over the adjacent finger tangency lines, but loose enough to provide relative longitudinal motion caused by swinging the trusses.

The outer fingers were then attached to the hull along their common tangency line. This change cured the slight rollup tendency, but further restricted the radial motion capability.

The ground board was raised to represent the partial cushion mode. This resulted in both inner fingers flipping into a second inflated mode condition, causing large cushion leakage. An ACV fitted with this skirt

configuration would be incapable of coming on cushion. It was demonstrated that the second inflated mode could be suppressed by either placing weights (0.35 kg (5 lb) on each finger 352 kg (5,000 lb) full scale) or by an elastic cable stretched across the two inner frames at their outer ends. Neither fix would be realistic at full scale.

The first attempts to insert the *Griffon* bow module into the fully inflated notch seal demonstrated a number of major problems with this approach. Fingers 4 and 5 did not slip against the bow and were rolled inward with the ship, severely loading the outer attachments to the support trusses. There is no reason to believe that this problem will cure itself at full scale, even with a reduced coefficient of friction between the fingers and hull.

In addition, fingers 4 and 5 were unable to completely close off a double triangular leakage area ahead and partly around the ship bow. With this leakage area and the rather poor sealing against the hull close to water level, the ACIB would fall off cushion.

3.1.3 Second Truss Tests

The second set of truss tests were conducted during the third week in September 1981, in order to make sure that the modifications to the rig as a result of the first series of tests did indeed cure the isolated problems.

The modifications consisted of adding two additional trusses at the ship bow interface, and attaching them to the fingers, remaking the truss hinge supports so that they were as close as possible to the finger/hull attachments, and developing two diaphragms to close off the air leakage around the ship bow.

These results were encouraging. The model ACIB now operated quite stably on partial cushion with no tendency for the inner fingers to roll upward. The new truss hinge locations cured the attachment loading problem, thus allowing free swinging action over the entire notch area. The additional vertical diaphragms sealed off the majority of the leakage around the upper bow area.

Figures 7 through 11 show the rig in its present configuration in all modes of operation.

3.1.4 Bow Seal Diaphragms

The bow diaphragms shown in figure 7 are the result of a large number of changes and small adjustments, and in their present configuration they are tailored to fit the CCG *Griffon* only. A new set will have to be

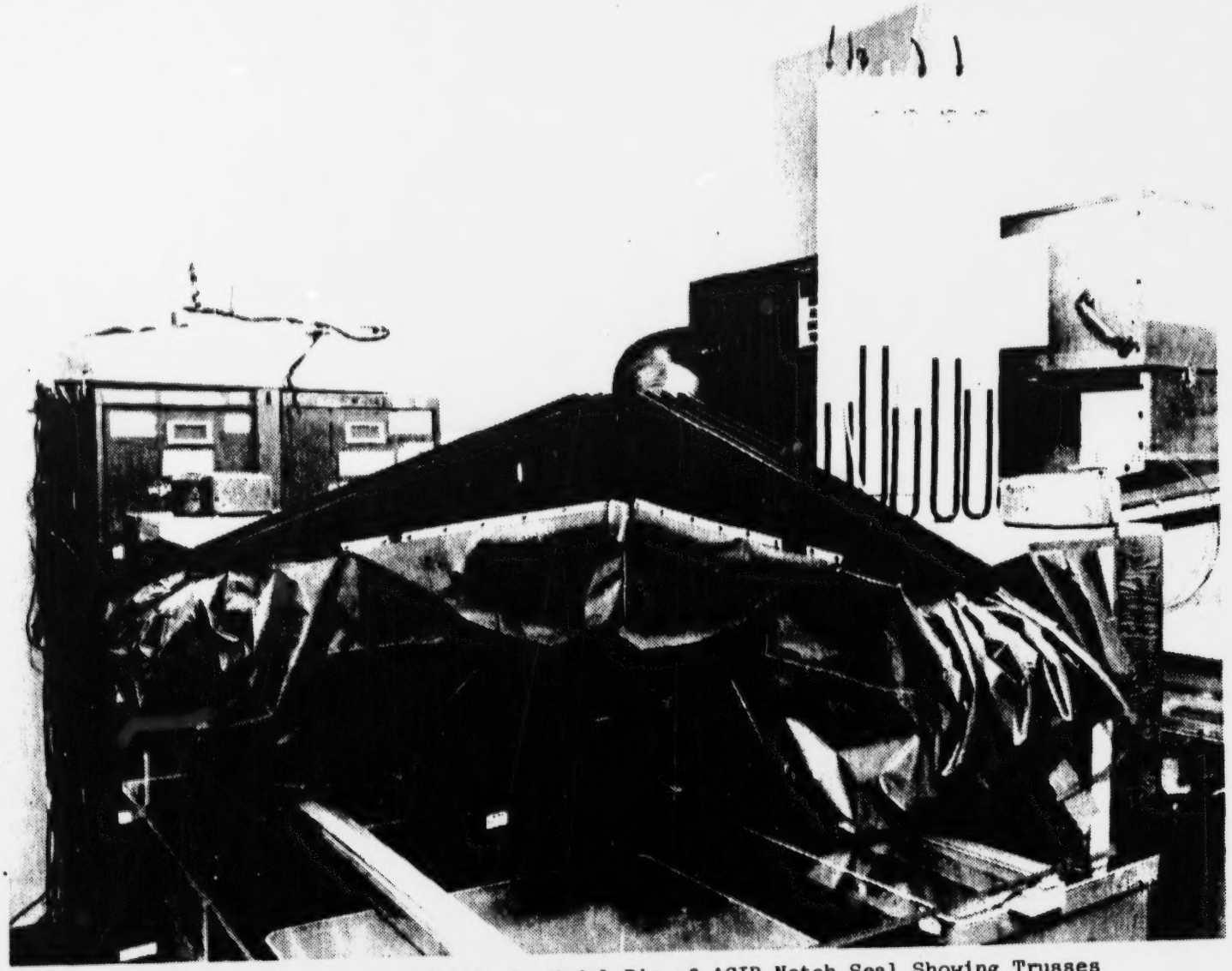


Figure 7 1/10-Sacle Model Rig of ACIB Notch Seal Showing Trusses Swung Open to Expose Vertical Bow Seal Diaphragms Tailored for CCG *Griffon*

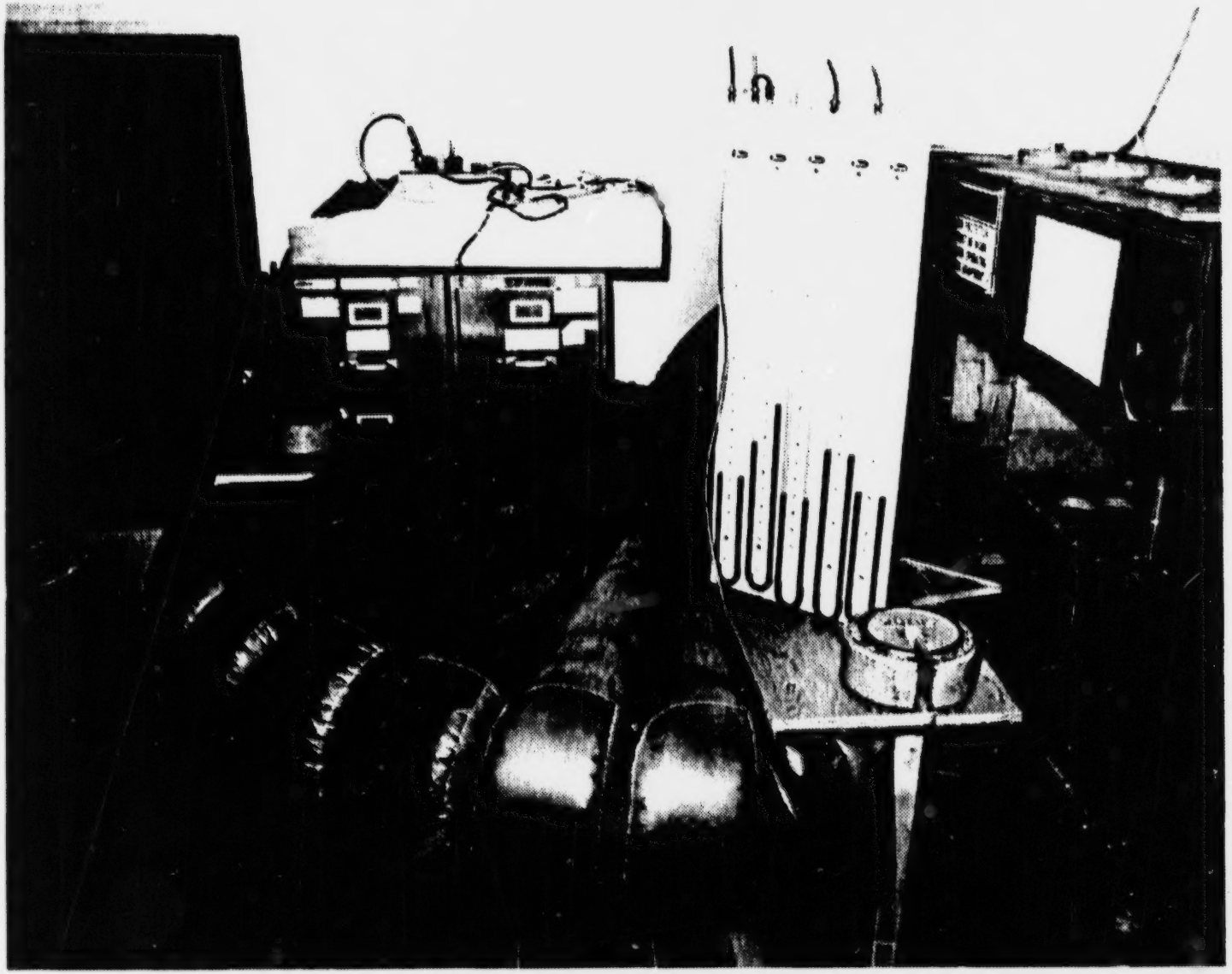


Figure 8 1/10-Scale Model Rig of ACIB Notch Seal in Fully Inflated Condition without Bow Module

Figure 9 1/10-Scale Model Rig of ACIB Notch Seal with the Bow Module of the CCG *Griffon* Fully Inserted

Figure 10 1/10-Scale Model Rig of ACIB Notch Seal Showing Bow Seal Diaphragms Inflated Against the Fully Inserted Bow Module of the CCG *Griffon*

Figure 11 1/10-Scale Model Rig of ACIB Notch Seal Showing the Bow Module of the CCG *Griffon* Fully Inserted Against the Pushing Rollers (Looking Up Through the Transparent Ground Board)

developed for the CCG *Alexander Henry*, at which time consideration will be given to the possibility of a universal design to fit the bow lines of most ships.

The current diaphragms can be made entirely from flat patterns for simplicity, and are attached to the pushing roller frame at their lower edges and the lower member of the centre trusses at their top edges. Their fabrication will require three panels in addition to suitable doublers and local peel stopping protected bolts.

Any competent sail or awning maker could construct them from drawings and flat patterns if the materials were provided.

3.2 Lift System Characteristics

Calculations comparing C_x versus rpm are in agreement in the normal operating range with those given in reference 2. However, they appear incorrect in predicting minimum rpm for on-cushion operation, (assuming $C_x = 0$). Figures 12, 13, and 14 present key lift system operating parameters as a function of fan rpm over the temperature range of interest. The skirt airgap shown assumes that a mean leakage of 6.35 mm (0.25 in) exists over and above that shown in the figures. In practice, it is expected that calculated airgap will not transpire as a continuous daylight gap under the fingers, but will occur locally beneath the finger junctions, particularly at the notch fingers.

Figure 15 shows the variation of fan speed with the temperature for three conditions:

a. Minimum rpm for on-cushion operation

b. An rpm to achieve the design flow ($C_x = 0.0165$)

c. Maximum rpm at which the engine is capable of driving the fan.

Figure 16 shows similar information as a function of vehicle weight at 0°C (32°F).

All of the above figures were generated using the fan characteristics with the IGVs fully open.

3.3 Comparison of Aluminium and Steel Trusses

A preliminary assessment was made of the aluminium tubing that would be required to give comparable strength to the two steel tube sections originally selected (4 in. × 4 in. × 3/8 in. and 5 in. × 5 in. × 1/4 in.). The comparison was based on the assumption that the tensile yield for steel

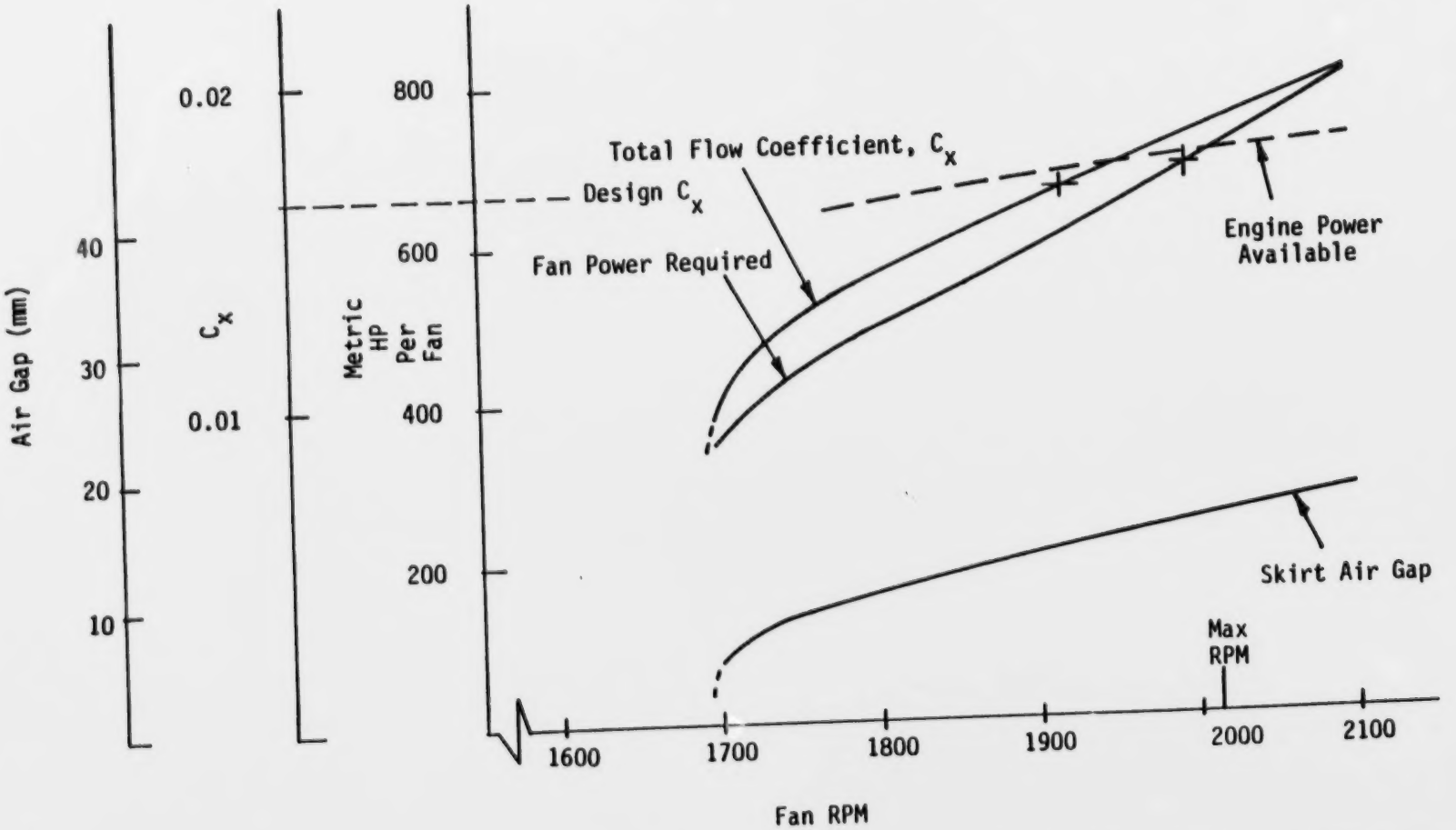


Figure 12 HSL-533 Icebreaker Barge - Lift System Operating Parameters, Gross Weight 253 Tonnes, Inlet Guide Vanes at Zero Degrees, Altitude 300 m, Temperature 30°C

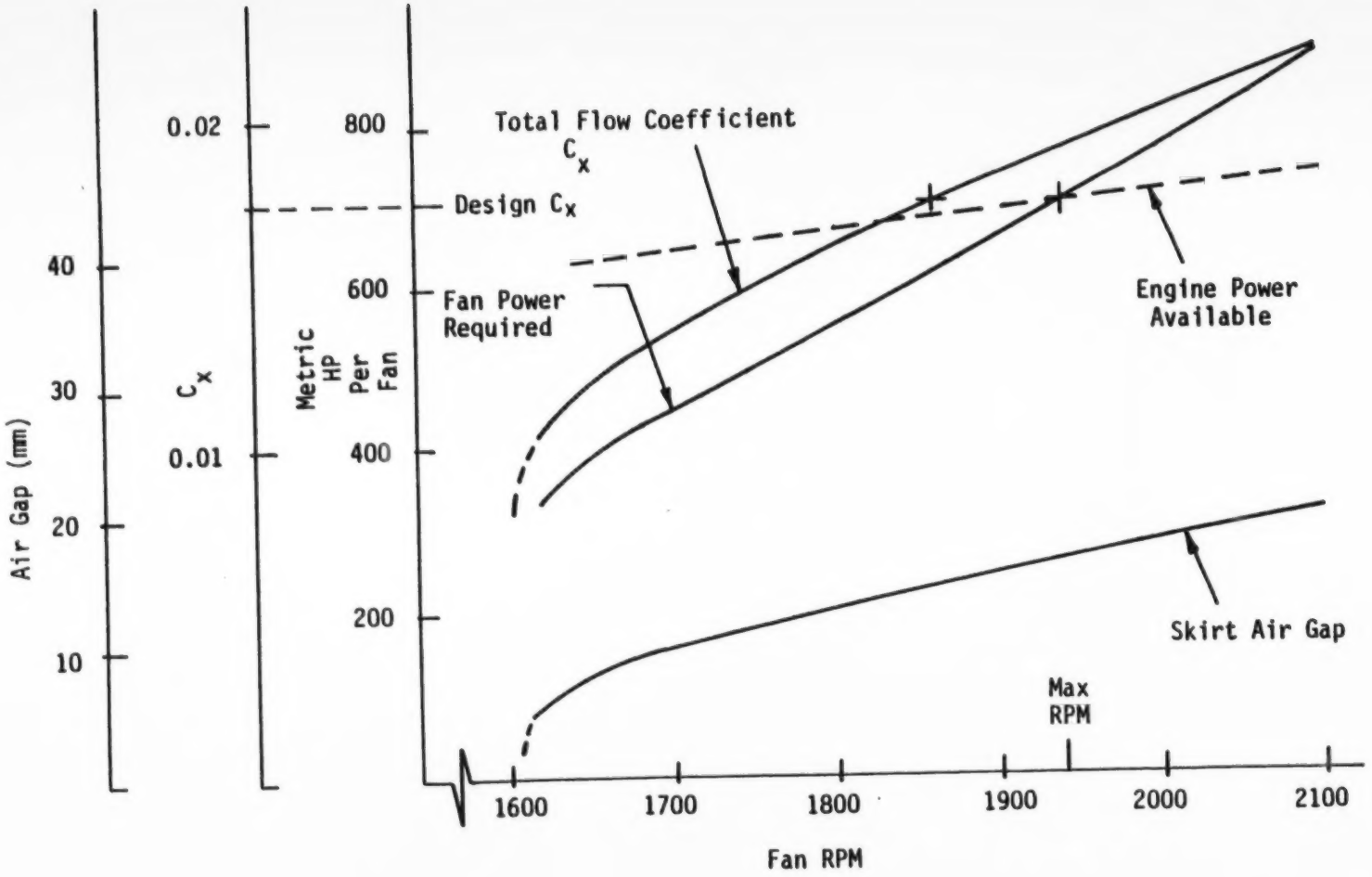


Figure 13 HSL-533 Icebreaking Barge - Lift System Operating Parameters, Gross Weight 253 Tonnes, Inlet Guide Vanes at Zero Degrees, Altitude 300 m, Temperature 0°C

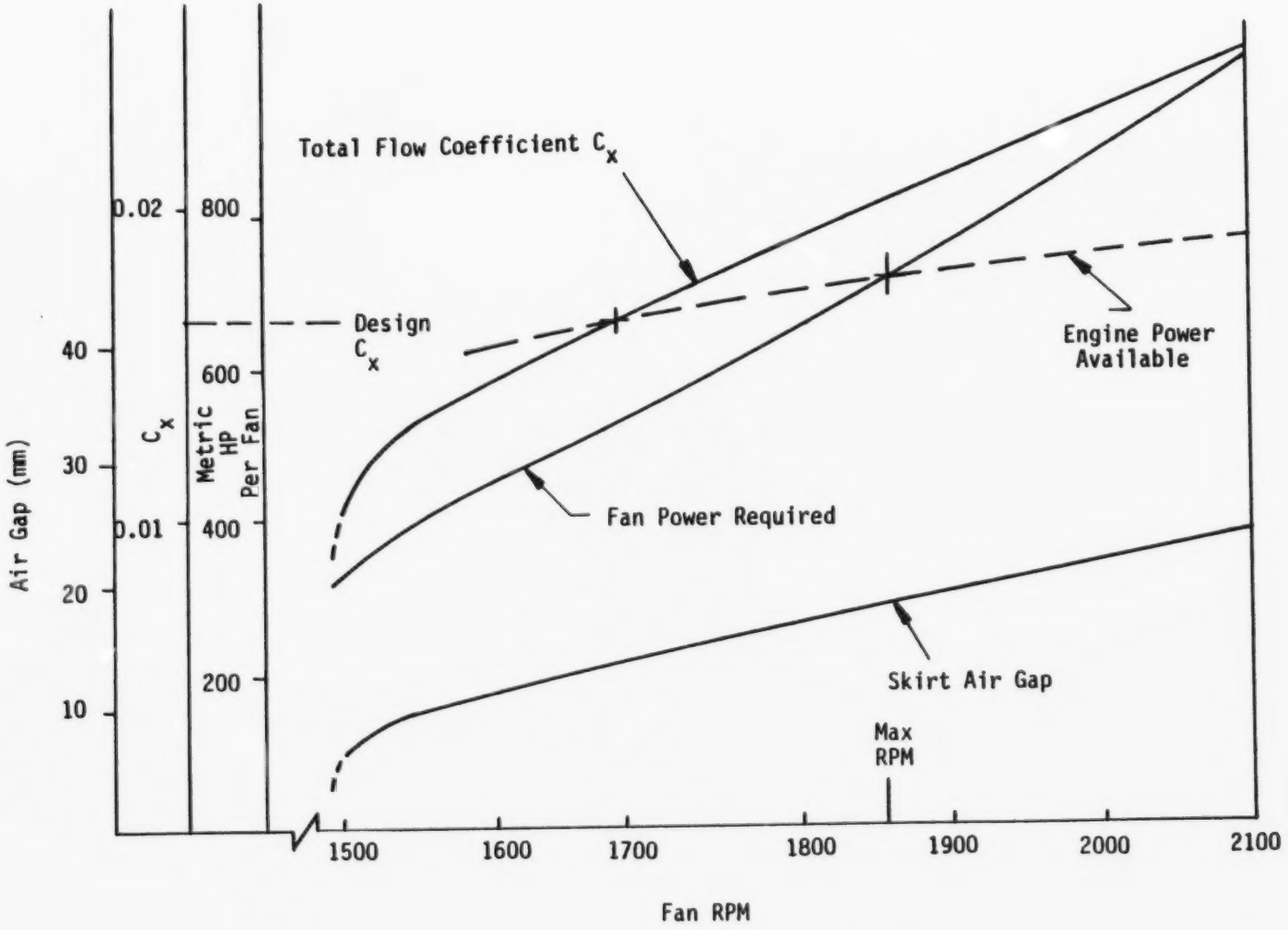


Figure 14 HSL-533 Icebreaking Barge - Lift System Operating Parameters, Gross Weight 253 Tonnes, Inlet Guide Vane at Zero Degrees, Altitude 300 m, Temperature -40°C

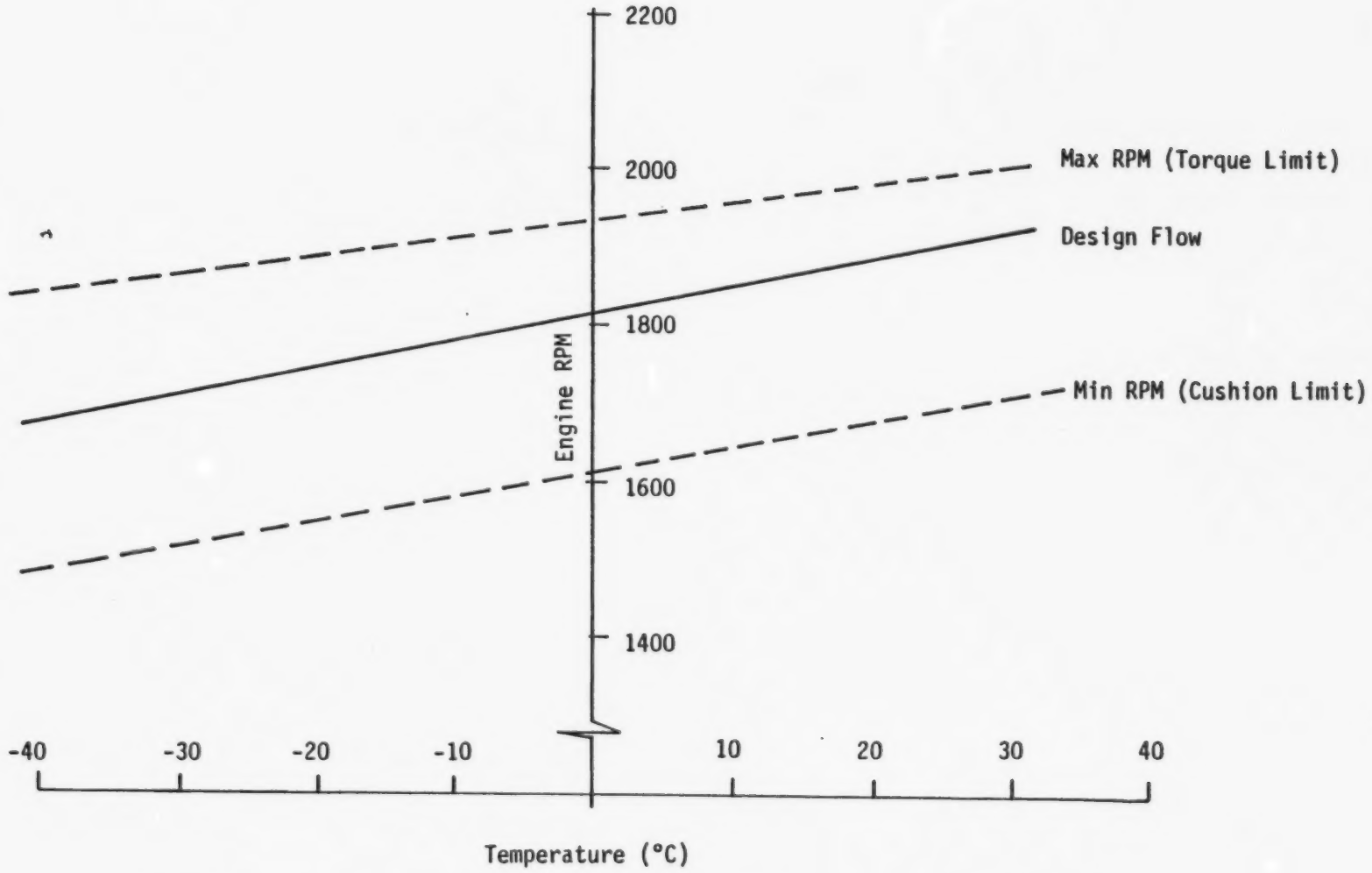


Figure 15 HSL-533 Icebreaker Barge - Operating RPM Range Versus Temperature, Gross Weight 253 Tonnes, Inlet Guide Vane at Zero Degrees

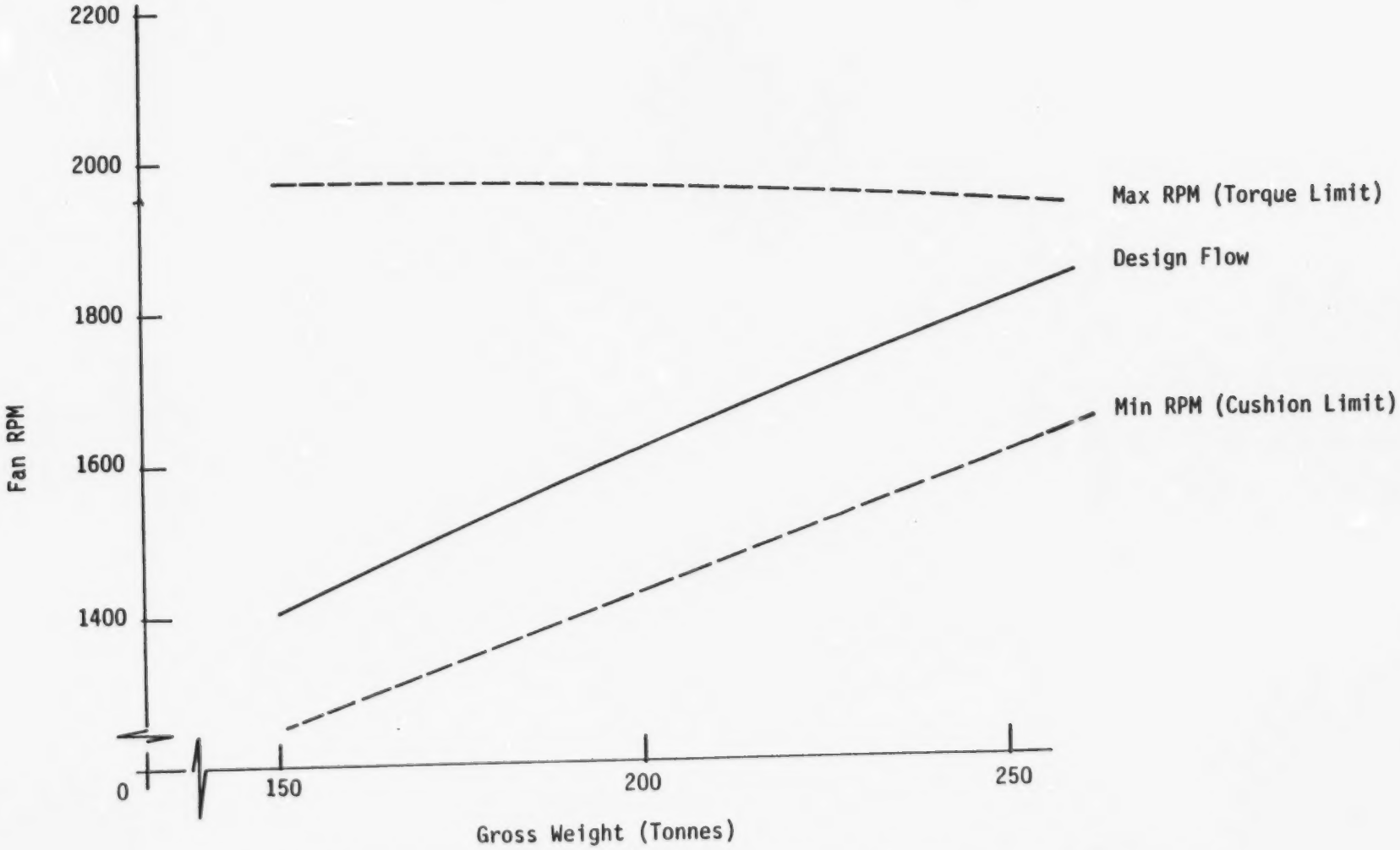


Figure 16 HSL-533 Icebreaker Barge - Operating RPM Range Versus Gross Weight, Temperature 0°C, Inlet Guide Vanes at Zero Degrees

equals 248,210 kPa (36,000 psi), and for aluminium equals 96,527 to 131,000 kPa (14,000 to 19,000 psi). Also, the density of aluminium equals one-third the density of steel. The 96,527 kPa (14,000 psi) yield is appropriate for the 0-temper condition, or in the as-welded areas. However, the allowable yield could be as high as 131,000 kPa (19,000 psi) for 5086-H112 plate material.

For tensile members of equal strength,

$$(\text{Area of Aluminium}) = (\text{Area of Steel}) \frac{(\text{Yield of Steel})}{(\text{Yield of Aluminium})}$$

and

$$\frac{\text{Weight of Aluminium}}{\text{Weight of Steel}} = \frac{\rho_a \sigma_s}{\rho_s \sigma_A} \qquad \frac{(1)}{(3)} \frac{(36{,}000)}{(14{,}000)} = 0.86$$

or,

for an aluminium allowable of 131,000 kPa (19,000 psi), the weight factor would equal 0.63.

The corresponding weight savings by converting all the steel structure to aluminium would be on the order of (1 - 0.86) × (9,070 kg) (or 20,000 lb) = 1,270 kg (2,800 lb) or, for the high allowable, the weight savings would equal 3,356 kg (7,400 lb).

For equal bending stresses, the I/y of steel beams must be multiplied by the ratio of allowables, 36,000/14,000 = 2.57, which results in 80.6 cm^3 (5.07 in^3) and 42.6 cm^3 (6.6 in^3), respectively, for the 4 in. × 4 in. × 3/8 in. and 5 in. × 5 in. × 1/4 in. steel beams. The corresponding values for aluminium would be 83.9 cm^3 (13.0 in^3) and 109.7 cm^3 (17.0 in^3) or 61.9 cm^3 (9.6 in^3) and 80.6 cm^3 (12.5 in^3) if the allowable was increased to 131 kPa (19,000 psi). This indicates that a 5 in. × 5 in. × 3/8 in. aluminium would be required at least in order to be comparable with the steel beam.

3.4 Hull Loads

3.4.1 Hull Loads Due to Pushing Post

Figure 17 shows a simple sketch of the ACIB in action and the various forces and reactions involved. It is assumed for simplicity that the reaction of the notch seal against the bow of the ship is exactly balanced by the cable loads, and that any moments due to misalignment of the forces are non-existent or negligible, a situation that may not be too far from the actual case in steady state conditions. It can be assumed, therefore, that the only load on the ship hull due to the pushing rollers will be caused by

D_D = Drag Due to Frontal Area of ACIB Skirt Climbing over Thick Ice Sheet.

D_F = Drag Due to Peripheral Skirt Contact with Broken Ice.

NOTE: Finger Load is Assumed Equal to Cable Load.

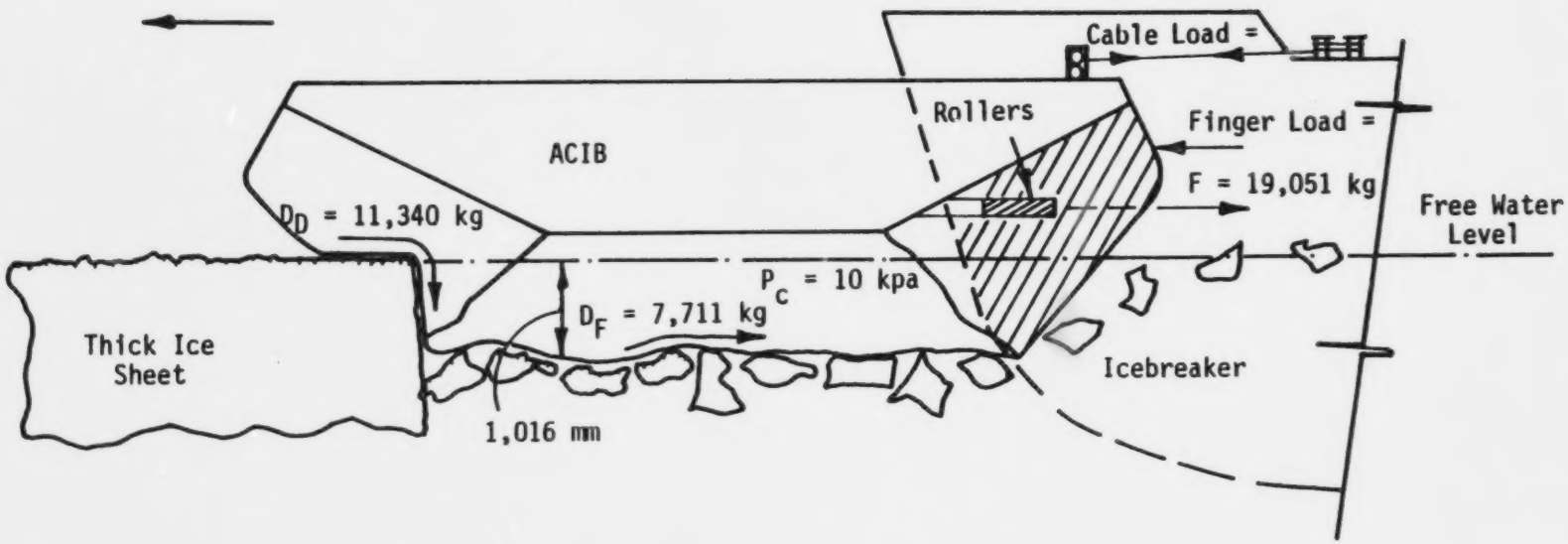


Figure 17 Assumed Worst-Case Situation for Pushing Roller Load Calculation

the drag of the bow portion of the skirt over the vertical face of the ice sheet and the friction loads generated at the fingertips around the periphery of the ACIB against the floating broken ice surface. It is also assumed for worst case purposes that the ice sheet being encountered by the ACIB is floating deeper in the water than the maximum cushion depression (that is, at least 1.02 m (40 in.)), and that its upper surface is level with the free water surface. Of course, in real conditions, ice this thick could not be broken by the ACIB, and the upper surface of the ice sheet would extend some percentage above the free water surface. Also, for reasons of simplicity, it was assumed that the ice sheet had broken up somewhat around the ACIB so that it fitted the bow profile exactly. The coefficient of friction between ice and rubberized skirt surfaces may vary extensively according to ice age, condition of the ice, and temperature. A value of $\mu = 0.35$ has been assumed (reference 3).

Under these conditions a friction drag load of 11,338 kg (25,000 lb) and 7,710 kg (17,000 lb), respectively, for the bow finger drag and fingertip drag were calculated, making a total of approximately 19,047 kg (42,000 lb) reacted by the pushing frame under the worst conditions. Since the two pushing rollers are pivoted asymmetrically and the roller rubber hardness is not known, only a rough estimate of the direct bearing loads on the hull can be calculated. Resolving the loads from the ACIB into normal loads at the CCG *Griffon* hull plating results in approximately 14,059 kg (31,000 lb) at each pushing roller. If 677 cm^2 (105 in^2) is assumed for the working flat on the roller, then a pressure of 2,035 kPa (295 psi) could be brought to bear on the ship's hull. (Note: Loads normal to the bow plating will vary according to the included bow angle.)

3.4.2 Hull Loads Due to Notch Seal

As it is presently envisaged, the ACIB will be brought on and off cushion with the notch fingers and bow seals making contact with the ship hull. The latter will thus be subjected to cushion pressure over an area of approximately 13.5 m^2 (150 ft^2), port and starboard, amounting to a pressure load of approximately 13,600 kg (30,000 lb). The contact area will move up and down as much as 10 feet as the ACIB comes on and off cushion. Relatively small friction loads will also be generated in the heave direction during these operations.

There will also be additional loads on the hull due to rollers, or bumpers, fitted to the inboard trusses to prevent direct contact with the hull. The hull loadings at these locations are not expected to be large, although they may occur above the normal bow reinforcing areas. Load predictions and their locations will be made during the next phase when the test rig data is available.

4. CONCLUSIONS

4.1 HSL-533 Inspection (August 1981)

a. The standard fingers are in relatively good condition and do not require modification or repair.

b. The notch fingers require repair and may require strengthening at their attachments to the hull.

c. The high pressure tubes, fittings, and braces should be removed entirely.

d. Projections from the standard finger attachments into the notch finger area should be removed and/or smoothed over.

e. The entire engine control and electrical system should be reworked.

f. The cushion air sealing around the deck area should be made good on reassembly.

4.2 Model Tests

a. The notch fingers will not inflate from rest without adequate air supply at their root attachments even with artificial support.

b. It is likely that the air supply to the notch fingers will be inadequate for lift-off over water.

c. The notch fingers are unstable without additional downward restraint, even when attached to each other over their entire length.

d. Pivoted trusses located over each finger junction provide the required upward resistance to stabilize the fingers if the two outboard fingers are attached to the ACIB hull and the adjacent sides of the two inboard fingers are also fitted with trusses.

e. The truss pivots should be located as close as possible to the adjacent finger attachments to the hull.

f. The trusses must be attached to their appropriate fingers along their length to obtain initial inflation and correct configuration at full inflation.

g. Two additional diaphragms are necessary to complete the seal around the stem of the ship bow. These may have to be tailormade for each mother ship.

h. Ship bow insertion into the notch seal with the ACIB on cushion is impractical with the proposed modifications, and would damage the inboard fingers if attempted.

i. Additional model development is required to perfect the connecting operation. Rollers and/or bumpers will be required on the inboard trusses to cushion hull contact.

j. The inboard notch fingers do not seal perfectly against the sides of the ship near the waterline and may result in a small loss of cushion height. It would not be practical to attempt a correcting modification within the available time period.

4.3 Lift System

a. The need for inlet guide vanes (IGVs) is not clear, and more analysis is required to fully investigate this area.

b. With one engine out, the remaining engines cannot turn the fans at the speed indicated in figure 10 of reference 2, and the ACIB may not remain on full cushion.

c. The use of IGVs will permit higher engine speed, but will probably result in little, if any, gain in total flow.

d. If fan inlet stacks are fitted, they must be of generous size to minimize pressure losses.

e. Provided residual/quiescent leakage at the structural connections and skirt attachments are minimized, the ACIB will achieve the specified minimum cushion height of 1.6 metres (over land) at the design flow.

f. At temperatures higher than 6.7°C (20°F), engine speeds greater than 1,800 rpm are required to generate the design flow. This should be acceptable, however, since the engines are rated at 2,100 rpm for crewboat use.

4.4 Hullborne Stability

a. The stability predictions made by CELL (reference 4) appear correct in most conditions checked by Bell.

b. It appears safe to assume that the ACIB will meet the bare minimum requirements of a positive metacentric height, and positive freeboard at the maximum displacement of 271 tonnes.

c. It should be stressed that there appears to be very little buoyancy margin. An overweight condition, icing, bow waves, ice and ship impact moments, leakage into the main buoyancy tanks could individually, or in consort, place the main deck under water.

d. Because of its configuration and mode of operation, the ACIB will have a plough-in tendency. The trim, weight, cushion flow, and speed conditions with respect to the plough-in boundary have yet to be determined.

4.5 Truss Design

a. The design of eight pivoted trusses located above the notch fingers to carry the unstable moments with the ACIB on cushion and to support the fingers prior to inflation appears feasible.

b. The design of the supporting structure requires further work to develop the best approach.

c. The entire truss and support structure could be built in either steel or aluminium with a weight savings of up to 3,356 kg (7,400 lb) with the latter, out of a total of approximately 9,070 kg (20,000 lb).

4.6 Engine Controls and Electrical System

All of the following should be performed as part of the next phase or work, so that the reassembly of the electrical system may be done correctly:

a. The original schematic drawings must be analyzed for accuracy and correctness of logic and function.

b. If possible, the as-built schematic drawings should be obtained from Northern Riglite and checked against the original schematics for deviations resulting from installation and/or test conditions.

c. If available, test logs or records should be analyzed to determine problem areas already discovered.

d. The electrical drawings should be corrected to account for determinations made above.

4.7 Hull Loads

a. Preliminary pushing load calculations indicate that in the worst conditions a force of approximately 14,059 kg (31,000 lb) could be applied normal to the CCG *Griffon* hull at the pushing roller locations. Pushing loads will be approximately 16 percent higher with the CCG *Alexander Henry*.

b. The two inboard notch fingers and diaphragm seals will apply a load of approximately 13,600 kg (30,000 lb) to the ship bow plates over the area of contact at the maximum weight conditions (P_c = 10 kPa (1.45 psi)).

c. Relatively light loads will be applied to the hull by the inboard finger supporting trusses. These loads and locations will be estimated during the next phase of the programme.

4.8 General

a. The major problem of the unstable notch fingers of the prototype has been overcome theoretically, and a fix has been demonstrated successfully at 1/10 full scale.

b. There is a lack of direct air supply to the notch fingers that could result in an inability to lift off over water, or that could produce excessive trim angles during lift-off.

c. A number of other problem areas, more or less severe, have been uncovered during the course of the HSL-533 evaluation, which if left unattended, could jeopardize the winter trial programme. However, no problem is seen at this stage that cannot be worked around prior to and during the initial tests.

5. RECOMMENDATIONS

Additional model tests should be conducted early in the next phase of the programme with a model of the CCG *Alexander Henry* to establish the correct configuration for the bow seal diaphragms and the proper location and design of inboard truss rollers and/or bumpers. At the same time, the ship connection procedures should be investigated with the aid of appropriate modifications to the test rig. These test will provide useful information for the full scale trials, in particular, the proper procedures for inserting the bow and coming on cushion.

It is also recommended that additional calculations are made in the following areas as soon as possible so that possible changes to the ACIB can be incorporated during assembly:

a. Stress analysis of the modified notch finger attachment loads

b. Assessment of winch capabilities and characteristics in the light of operating procedures and predicted loads (it is noted that winch foundation loads have not been checked, reference 5)

c. Evaluation of alternative methods for providing direct airflow to the notch fingers for waterborne operation.

It is believed that there are plans to reposition the wheelhouse farther away from the notch in order to avoid possible contact with the ship bow. The model tests have confirmed this vulnerability, particularly when the ACIB is off cushion. The proposed truss support is in danger of contact during partial cushion operation and it is recommended that consideration be given to some form of positive restraint or separation, to prevent this from occurring.

In view of the possibility of a plough-in occurence at the higher operating speeds with full ballast, it is recommended that personnel are kept off the ACIB while these tests are underway, or until the plough-in characteristics have been thoroughly investigated and the necessary steps have been taken to preclude any such event.

Finally, in view of the very minimal aft end freeboard and limited overall buoyancy, it is recommended that additional flotation be seriously considered. The buoyancy margins should probably be increased before the heavy weight condition is considered.

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5. Structural Analysis of Air Cushion Platform (Calgary: Hoverlift Systems, Ltd., Transport Canada, Air Cushion Vehicle Division OSQ Report No. 79036, Lloyd's Register of Shipping Calculations, April 1979).